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INTRAPLATE EARTHQUAKES AND STATE OF STRESS IN THE FORMER SOVIET UNION

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Information on intraplate earthquakes in the Former Soviet Union and adjacent regions is collected from historical and instrumental records. Since most of the territory of the Russian Republic is intraplate in its tectonic character, intraplate earthquakes and the stresses that generate them are of importance to the monitoring of the Comprehensive Test Ban Treaty (CTBT). Data from a number of catalogs are merged so as to study locations and sizes of intraplate shocks and their tectonic setting in Russia, Belarus, Ukraine, Kazakhstan and the Baltic states. In these areas intraplate activity is generally highest in regions 100 to 300 km wide adjacent to the more active plate boundaries in the Carpathian, Caucasus and Kopet Dag mountains and, hence, drops off gradually rather than suddenly in space. In contrast, earthquake activity drops off very abruptly to the north and northwest of the active zone along Lake Baikal. An east-striking zone of intraplate activity about 700 km long near 56^{o} N between 43^{o} and 54^{o} E, which coincides with portions of the Volga and Kama rivers of the same strike, is delineated for the first time. As in North America some intraplate areas of Eurasia are characterized by very low rates of known seismic activity. The seismic event of August 16, 1997 in the Kara Sea, a small intraplate earthquake of magnitude 3.2, was studied extensively. A few new directions of principle stresses are obtained for intraplate areas of the Russian Republic.

INTRODUCTION

Intraplate Earthquakes

Most of the world's earthquakes are located along the boundaries of the lithospheric plates that make up the surface of the earth where rates of deformation are highest. Nevertheless, the interiors of plates, i.e. intraplate regions, are not totally rigid and have been the sites of known seismic activity. Some of the largest historic earthquakes within plates, so-called intraplate shocks, include the New Madrid series of large events in southeastern Missouri and northeastern Arkansas of 1811-1812, the Charleston SC event of 1886, several large historic earthquakes in the St. Lawrence Valley, the Grand Banks shock of 1929, several earthquakes of magnitude, M, about 6 in central and western Australia during the last 25

years, and the recent Indian earthquake southeast of Bombay with its great loss of life. Geologic excavations have detected liquefaction features associated with pre-historic intraplate earthquakes near New Madrid and in the Wabash Valley of Illinois and Indiana. The Meers fault in Oklahoma was the site of a large to great shock several thousand years ago but exhibits little activity today. Intraplate shocks are known to have occurred in every continent and within many older oceanic areas (Sykes, 1978 ; EPRI, 1994).

The United States Government has been involved for nearly 50 years in monitoring nuclear explosions conducted by the Former Soviet Union (FSU), China, other nuclear weapons states. Since the Limited Test Ban Treaty entered into force in 1963, all U.S. and Soviet nuclear explosions have been conducted underground. Since then, a prime task of nuclear monitoring has been the identification of seismic signals with high reliability as being generated by either nuclear explosions or earthquakes. After 20 years of great emphasis on the determination of yields of nuclear explosions in the U.S.S.R. to verify compliance with the Threshold Test Ban Treaty (TTBT), however, the U.S. and other countries have returned again to placing prime importance on monitoring compliance of the 1996 Comprehensive Test Ban Treaty (CTBT) and hence on the discrimination of small seismic events.

For many years U.S. efforts in nuclear monitoring have involved either test sites in the FSU or the more seismically active parts of that large country. About 75% of the earthquakes in the FSU occur along the Kuril and Kamchatka subduction zones. The rock types in those volcanically active areas are not useful for conducting decoupled nuclear explosions. Hence, those areas need not be monitored down to as low a magnitude as regions in which rocks exist (mainly in salt domes) that might be used for conducting small decoupled nuclear tests. The distribution of earthquakes in the Kuril-Kamchatka region is well known and their mechanisms understood as is the nature of the subduction process. In addition to being able to monitoring those active regions with conventional seismic arrays, the Kuril-Kamchatka region can also be monitored by submarine acoustic systems since those areas border the Pacific Ocean.

The second most active region of the FSU extends in a diffuse belt along its southern border. With the breakup of the U.S.S.R. much of that activity, however, is not located in the Russian Republic but in several new

republics in Central Asia and the Caucasuses. Activity in that broad belt is now more easily monitored using seismic stations in Mongolia, China and those new republics as well as from the Russian Republic itself.

That part of the FSU that is now within the Russian Republic consists mainly of old geologic and tectonic terraines that are located either far from plate boundaries or near but not within its more active areas. Most past seismic stations operated by the U.S.S.R. were situated in what are now those new republics or in the Kuril-Kamchatka region. Very little work was done either by Soviet or other scientists to study intraplate shocks outside of the two most active regions of the FSU. Seismic catalogs with durations of decades extend down to small earthquakes, i.e. to M 3 or 4, mainly for Central Asia, the Caucasus region and Kuril-Kamchatka. For most other regions they are completely only for M > 4.5. Data from the stations of the International Monitoring System are complete down to smaller magnitudes but generally for a shorter time period.

One famous intraplate shock of magnitude near 5 occurred in March 1976 within the former nuclear test site in eastern Kazakhstan. While some workers thought initially that the 1976 event was a nuclear explosion (mostly on the basis of its location and the fact that it, like nuclear explosions, was not listed in the Soviet yearly seismic bulletin), subsequent modeling of the seismic waves by British investigators showed conclusively that the event had a mechanism that was definitely that of an earthquake. Several small events in and near Novaya Zemlya of magnitude 2.3 to 4.3 since 1986 have been extensively studied and identified as intraplate earthquakes.

Hence, it is clear that intraplate earthquakes in the FSU are a class of earthquakes that must be identified as such and dealt with under a CTBT. Future events of that type are likely to occur in areas in which many propagation paths to seismic stations are as yet poorly calibrated. Intraplate earthquakes in general are poorly understood compared to earthquakes along active plate boundaries in California, Japan, Alaska and the Kuril-Kamchatka region.

Scientists at Lamont and St. Louis set up some of the first seismic networks specifically to study intraplate earthquakes. Lamont has operated a network of about 25 stations in New York, New Jersey and Vermont to study intraplate activity since 1971. Sykes (1978) published

the first extensive review of intraplate earthquakes and intraplate magmatism, which included North and South America, Africa, Australia and Europe. For the past decade the Electric Power Research Institute (EPRI) has sponsored a massive study of earthquakes in so-called Stable Continental Regions (SCR), a subset of intraplate areas that excludes regions like the Rocky Mts. that have been affected by tectonic movements as young as early Cenozoic. That work was motivated by the need to have better information on the occurrence of intraplate shocks in central and eastern North America where most of the nuclear power plants of the U.S. are situated. The EPRI study, which consists of a series of volumes published in Dec. 1994, can be taken to mark the end of a second generation of work on intraplate earthquakes. It concludes that large earthquakes in intraplate regions are more likely to occur in areas that experienced extensive rifting during the Mesozoic and/or magmatism as recently as early Tertiary.

Neither the EPRI study nor the work of Sykes (1978), however, devoted much attention to intraplate activity in the FSU as we do in this study. With the greater availability of seismic data from the FSU and the necessity to identify small seismic events in intraplate regions of the FSU under a CTBT, we began a third generation of work on intraplate earthquakes, stresses and other intraplate tectonic phenomena. Unlike many other countries, however, some felt reports of earthquakes are available from records of monasteries in the Ukraine, Belarus and the western part of the Russian Republic that extend back about 800 years in time. China is probably the only country with a longer record of intraplate earthquakes.

Stresses within Lithospheric Plates

Knowledge of the state of stress within the crust is vital to an understanding of intraplate shocks as well as to a variety of the other societal uses. Some of the first measurements of stress *in situ* were made in the 1950s in conjunction with problems of mine stability and rock bursts by the U.S Bureau of Mines, the South African gold mining industry and engineers in Scandinavia. Sbar and Sykes (1973) compiled information on the directions and magnitudes of principal stresses in central and eastern North America that were made far enough away from mine openings that they could be considered to be representative of

stresses in the earth's lithosphere and not stress concentrations related to underground openings. Their work was the first to emphasize stress measurements as a geophysical tool, rather than solely as a technique to insure mine safety. They included information from hydrofracturing performed in boreholes, deformation of underground openings, strain relief (mainly overcoring) measurements in mines, post-glacial geologic "pop-up" features such as those in northern New York State, and directions of maximum compressive stress as inferred from focal mechanism solutions of earthquakes.

Sbar and Sykes concluded that the directions of maximum compressive stress were oriented about N60^{o}E in much of central and eastern North America, a feature that is even more evident in the more numerous data points in the recent World Stress Map Project (Zoback, 1992a,b). These two generations of work on stresses in the crust also found that maximum compressive stresses are usually oriented horizontally, which indicates that the stress tensor consists of a significant tectonic component. (Maximum compression should be vertical and about three times larger than horizontal compressive stresses for a so-called relaxed state of stress that results from merely "turning on" gravitational acceleration). Those working on stresses in the earth's lithosphere have found that measurements made shallower than 100 to 300 m generally are not representative of deeper measurements. The presence of weathering and crack formation in that outermost part of the crust results in relaxation of stress.

The entire issue of the *Journal Geophysical Research* for 30 July 1992 is devoted to the World Stress Map Project. Dense measurements of the directions of maximum horizontal compressive stress using a number of techniques are now available for large areas of North America, Australia, the Middle East and Europe (Zoback, 1992a). One area of very poor coverage on their world map is the large intraplate region of the Former Soviet Union. Only a few measurements are shown for the central Ural Mts. and the Karalia and the Kola Peninsula. Stresses are known to be high at and near the former test site in Eastern Kazakhstan.

The consistency in the directions of maximum compressive stress in well-studied intraplate regions and the fact that they are generally oriented in the direction of absolute plate motion (with respect to the hot

spot reference frame) indicates that intraplate stresses are generated at least in part by forces at plate boundaries and are transmitted long distances within plates. It is surprising that the stress field in northern Europe and North America does not appear to be influenced mainly by mantle flow resulting from the removal of the last Pleistocene ice sheets since large vertical motions related to that effect are still observable (e.g. Gregersen, 1992). Unlike those areas, however, much of the Russian Republic was not covered by continental ice sheets during the last glaciation. Thus, a comparison of intraplate earthquakes in those areas with those in Scandinavia and North America is important in understanding the origin of intraplate shocks and stresses. It may be possible to distinguish glacial unloading as a factor in controlling, at least in part, intraplate activity in northern Eurasia.

WORK ACCOMPLISHED

This report details work accomplished on studying intraplate earthquakes and stresses in the Former Soviet Union during the last two years. We believe that we have made much progress in studying intraplate shocks in that area but we have added only a few new reported stress measurements to the several previously published in the western literature. It should be remembered that the proposal was for a two year program but that funding for a second year was eliminated just prior to the award of the contract in 1996 and that the budget for the first year also was reduced.

Nevertheless, in the past year Sykes and T. Rautian from Lamont along with S. Yunga from Moscow compiled a series of catalogs of historic to recent intraplate shocks in the Former Soviet Union (FSU) and surrounding regions. Yunga spent the months of June 1997 and 1998 working on the project at Lamont. He is probably the world's expert on intraplate earthquakes, their focal mechanisms and measurements of *in situ* stress in the FSU.

Intraplate Areas where Events were Cataloged and Studied

Data were collected for a wide territory of continental Eurasia (Latitude 35^{o}-70^{o} N and Longitude 22^{o}-122^{o} E) and for the Arctic region to the north of Eurasia (70^{o}-90^{o} N and 0-150^{o} E). This broad region was divided

into 4 subareas and 18 regions as listed in the table below. It includes intraplate as well as active areas.

Region Latitude Longitude

ARCTIC 70-90 N; 0-150 E;

WESTERN REGION (EUROPE):

- NORTHERN RUSSIA 60-70 N; 28-50 E;
- BALTIC 52-60 N; 20-30 E;
- CENTRAL RUSSIA 52-60 N; 30-50 E;
- UKRAINE 46-52 N; 22-40 E;
- CRIMEA 44-46 N; 28-40 E;
- SOUTHERN RUSSIA 44-52 N; 40-50 E;
- CAUCASUS 39-44 N; 39-51 E;

CENTRAL SUB-AREAS:

- NORTHERN URALS 58-70 N; 50-80 E;
- SOUTHERN URALS 50-58 N; 50-80 E;
- NORTHERN KAZAKHSTAN 44-50 N; 51-80 E;
- TURKMENIA 35-44 N; 51-65 E;
- CENTRAL ASIA 35-44 N; 65-80 E;

EASTERN SUB-AREAS:

- WESTERN SIBERIA 58-70 N; 80-120 E;
- ALTAI-SAYAN 45-58 N; 80-100 E;
- BAIKAL 50-58 N; 100-122 E.

The data we cataloged were taken from the following sources:

Russian/Soviet Catalogs:

ESSN 1962-1990; 44,980 events (the annual "Earthquakes in the USSR");
OBN1955-1996; 21,741 events (Obninsk Catalog);
SMG 1970-1988; 230 events (SevMorGeo - Northern Seas Geology)
GNRL -550-1997; 30,988 events (new General Catalog),
HIST -550-1961 9,800 events (Historical Catalog)

The General Catalog (GNRL) includes some historical data, as well as instrumentally-recorded earthquakes that occurred before the ESSN and OBN catalogs were established. In some cases earthquake data were included in the GNRL from western sources (e.g. ISC). HIST is a new version of the historical catalog of earthquakes based on the Shebalin-

Kondorskaya "New Catalog", which consists mostly of data from the General Catalog for the time interval before 1961 and includes additional published data from the book "Seismic Regionalization" and the catalogs of Ananin, Ananin and Nikonov, and other Soviet and western European publications.

Western sources of data:
ISC 1994-1987, 14,500 events
NEIC 1989-1994 3,093 events
IDC 1995-1996 5,096 events
NAO (Norsar) 1986-1989 22 events

Our final catalog was created from the above sources. Several of the catalogs we used omit chemical explosions. We eliminated nuclear explosions and, so far as possible, we tried to eliminate chemical explosions since our object was to study intraplate earthquakes. We eliminated recent events of magnitude, M, less than 2.5 since the reporting of events of that size is still very inhomogeneous for an area as large as Eurasia. Most aftershocks were eliminated. We then eliminated shocks in active areas of Eurasia and in so doing reduced the number of events in the catalog considerably.

Fig. 1 shows activity in the intraplate areas we describe further in the 13 parts of Fig. 2. White lines to the northeast of the Carpathians (Fig. 2.3) and to the north of Crimea (Fig. 2.4), the Caucasus (Figs. 2.10 and 2.11) and the Kopet Dag (Fig. 2.12) mark what we take to be the boundaries between activity along plate boundaries and adjacent intraplate areas. Epicenters are not shown in the active areas of those subfigures. We did not include in our study Mongolia, Turkey, the Balkans, much of the Black Sea, the Russian far east nor the diffuse boundary between the North American and Eurasian plates in the northeastern part of Russia.

A wide variety of seismic magnitudes and other measures of earthquake size have been reported for the intraplate events we examined. For a given event we gave preference to the first available measure of size in the following list: M_s, m_b, MPA, MPB, MLH, Obninsk magnitudes (M-1, M-2, M-3), the energy class k as deduced from seismograms, and the maximum intensity reported, I. We used relationships derived by Rautian to reduce various measures of size to a

single magnitude, M, which corresponds to M_S (or M_W) for large events and m_b for moderate to small shocks. Much work remains to be done in deriving more consistent and uniform measures of magnitude for the vast areas we examined. We did not attempt to correct magnitudes of very small events that were recorded by only a few very sensitive stations for biases that often result in overestimates of m_b.

Distribution and Sizes of Intraplate Earthquakes in the Former Soviet Union

In the 13 parts of Fig. 2 we show intraplate earthquakes from our combined catalog. Several of the events in the catalogs are new to workers outside the FSU. Some of the historic events to the west of the Ural mountains extend back to the Middle Ages. Care must be exercised in comparing rates of activity in the various parts of Fig. 2 since we plot all known earthquakes regardless of their date of occurrence. The catalogs are quite inhomogeneous in their completeness among the various areas of the FSU. Our main aim at this point, however, is to delineate zones of intraplate activity.

Known seismic activity to the east of the Urals (not shown in a separate figure) is quite low once known or suspected chemical explosions are removed. The historic and instrumental record for that large region, however, is short. Nevertheless, it appears to have a lower rate of activity than the central Urals (Fig. 2.6) and some parts of western Russia. Fig. 3 shows earthquakes from the ESSN catalog from 1962 to 1990. Seismicity drops off abruptly in going from the active zone along Lake Baikal into the craton to the north and west. The solid line in Fig. 3 is taken to mark the approximate boundary of active and intraplate areas.

Activity in intraplate regions of Eurasia is generally lower than that in North America and Australia. No intraplate shocks of $M > 7.3$ have been identified for Eurasia whereas intraplate events as large as about M 8.0 have occurred historically in North America (EPRI, 1994; Triep and Sykes, 1996, 1997). The largest known earthquakes in intraplate regions of the Russian Republic and surrounding areas are the Gazli shocks of 1976 (Fig. 2.12). Whether the Gazli events were triggered by fluid injection related to petroleum exploitation is still debated.

The largest known historic events in areas 1 and 2 of Fig. 2 are about M 5. Activity, however, is higher in a 300 km zone to the north of the active Carpathian region of the FSU (Fig. 3.3) where the largest historic shocks in the Russian platform have occurred with magnitudes up to 6.5. Similarly, activity extends well north of the active zone in the Crimea in and near the Sea of Azov in areas 3 and 4 with events as large as M 5.5. Also, activity is found up to 150 km to the north of the main plate boundary in the Caucasuses in areas 9 and 11 and up to 400 km to the north of the mountain front and main plate boundary in the Kopet Dag to the east of the Caspian Sea in area 12 if the Gazli shocks of 1976 near 40° N, 64° E are included. While a few of the events to the north of what are taken to be the active plate boundaries in the Carpathians, Crimea, Caucusus and Kopet Dag may be mislocated, many others are well enough located to indicate that they occurred in a "penumbra" zone adjacent to but not within the main plate boundary zone. Each of these zones is adjacent to an active zone of compressional tectonics in which seismicity decays away spatially on a distance scale of 100 to 400 km. Each of those zones may be considered to be a "plate boundary related" zone of activity. This is in contrast, however, to the much more abrupt decrease of activity to the north and northwest of Lake Baikal, a zone of extensional tectonism (Fig. 3).

One of the most interesting intraplate features that we identify extends for about 700 km along 56° N latitude in Figs. 2.5 and 2.6 from 43° to 55° E. The Volga River changes its overall southerly direction to easterly at 44° E at that zone and then resumes a southerly course at 49° E. The easterly trending portion of the Volga and the zone of seismic activity follow the northern side of the Volga Highlands (Fig. 2.5). The zone of seismic activity continues east along the Kama River from 49° to 54° E (Fig. 2.6). The shock of 1596 of M 5.5 is the largest known event along the zone. While many large reservoirs exist in the areas of Figs. 2.5 and 2.6, epicenters do not seem to correlate with the occurrence of large reservoirs.

Intraplate activity is moderately high along the central Urals in Fig. 2.6 but known shocks in Fig. 2.7 are mostly concentrate well to the west of the northern Urals. No known activity was identified along the southern Urals to the south of 53° N (Figs. 2.6 and 2.8). The shocks of 1693 and 1914 of M 5.5 are the largest known events along the central Urals.

Some activity up to M 5 is seen in the Pre-Caspian depression in Fig. 2.9. It appears to cease near the north-south boundary in topography along 45° E, which also marks the geological boundary between the Ukrainian shield and the very different geology of the Pre-Caspian depression. The depression consists of up to 20 km of sediments of post-Devonian age that may be floored by oceanic crust of Devonian or earlier age, which has not been subducted.

Fig. 2.13 shows known earthquakes in the Melkosopochnik region. The largest known shock is that of March 1976 of M 5.1, which occurred within the former nuclear test site in eastern Kazakhstan.

Stress Measurements

We were not successful in obtaining much new information on the state of stress in intraplate areas of the FSU. Measurements of stress tend to be scattered among different disciplines such as mining, petroleum engineering, geophysics and geology. Reports of stress measurements or of data that could be used to infer the state of stress tend to published in a wide variety of journals and reports. This is even more severe for the FSU where those disciplines were (and are) practiced in different institutes that often do not interact with one another. The intraplate area of the FSU still is poorly covered in terms of measurements of stress compared to intraplate areas of North America, Australia, and northern Europe.

Focal mechanisms of shocks in the Kara Sea in 1986 (M 4.3) and in the Melkosopochnik region in March 1976 (M 5.1), like those in many intraplate areas of continents, are characterized by a significant compressional component as are composite mechanisms of events in the Tatarstan oil field near 55° N, 52.1° E (Mirzoev et al., 1996).

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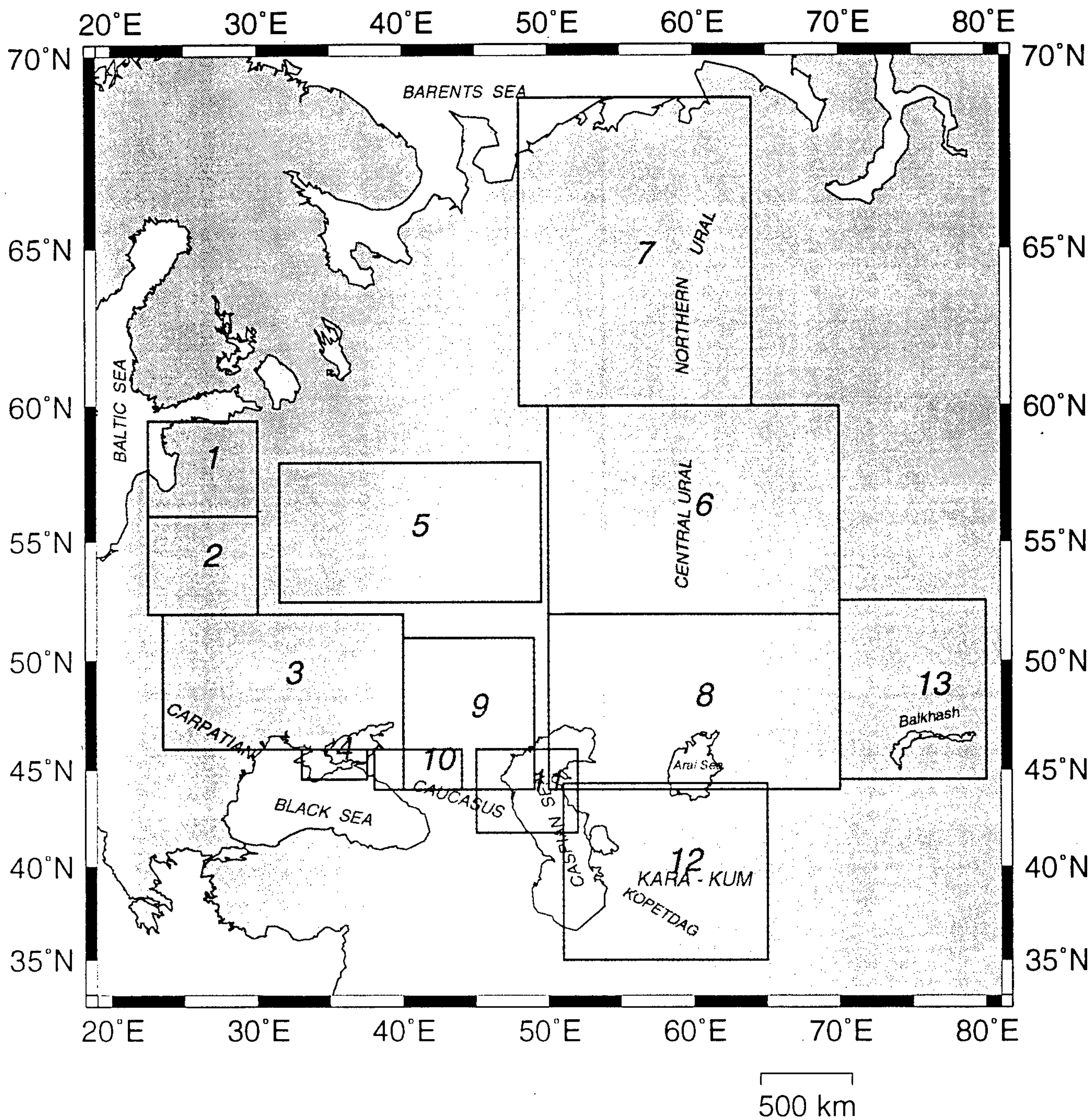
FIGURE CAPTIONS

Fig. 1. Areas in which intraplate earthquakes were investigated in detail. Numbers correspond to subfigures of Fig. 2.

Fig. 2. Intraplate earthquakes in 13 areas shown in Fig. 1. In the various sub-figures symbol shown as M 5.0 is used for events of $4.5 \leq M \leq 5.4$, etc.

Fig. 3. Earthquakes near Lake Baikal from 1962 to 1990 of energy class K from 8 to 15. Note abrupt decrease to north and northwest of line that is taken to divide active and intraplate regions.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40°E
50°E
60°E
70°E
80°E
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
BARENTS SEA
BALTIC SEA
NORTHERN URAL
CENTRAL URAL
CARPATIAN
BLACK SEA
CAUCASUS
CASPIAN SEA
Aral Sea
KARA - KUM
KOPETDAG
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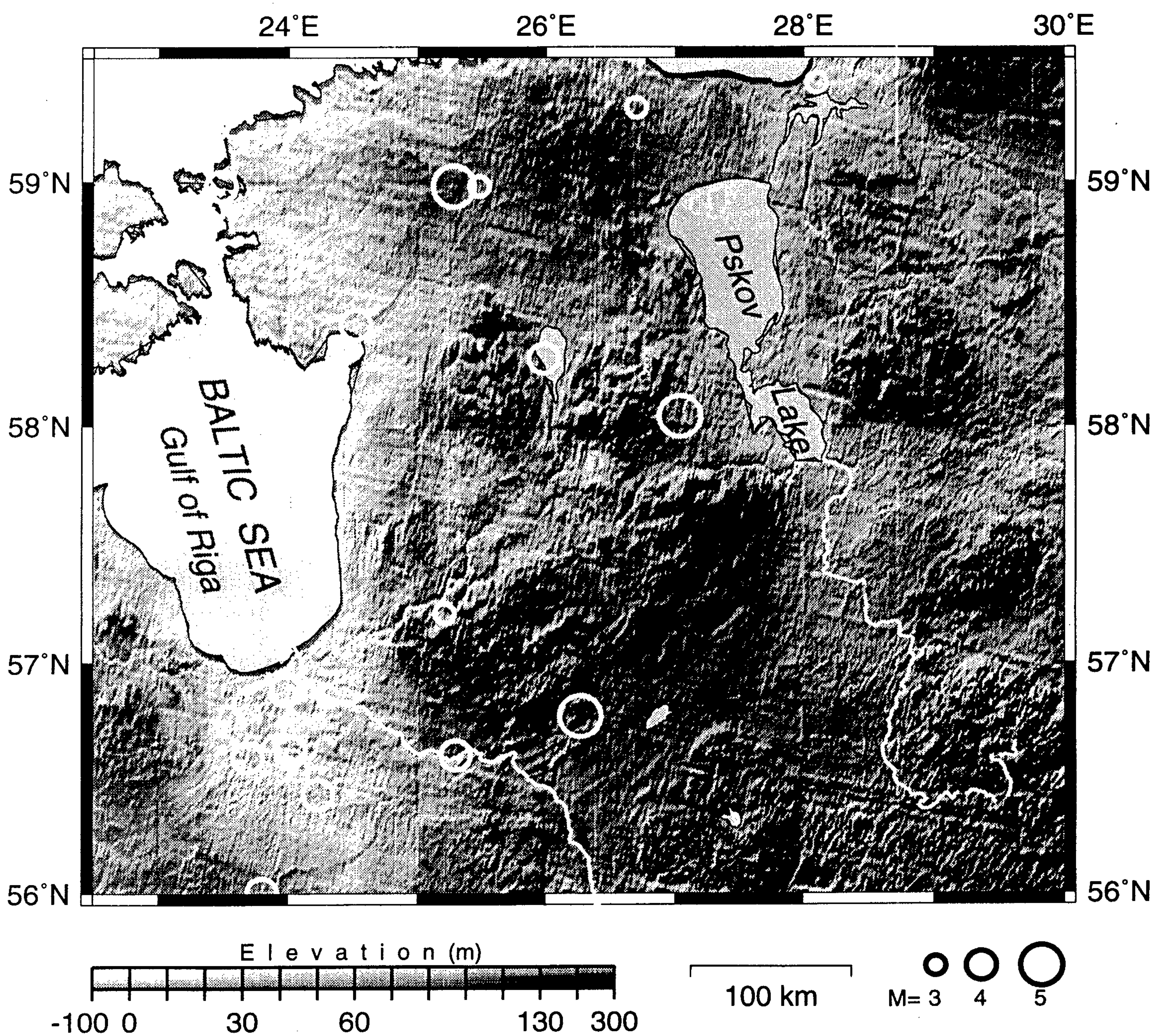
11
12
13
500 km

Figure 1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26°E
28°E
30°E
59°N
58°N
57°N
56°N
Pskov
Lake
BALTIC SEA
Gulf of Riga
Elevation (m)
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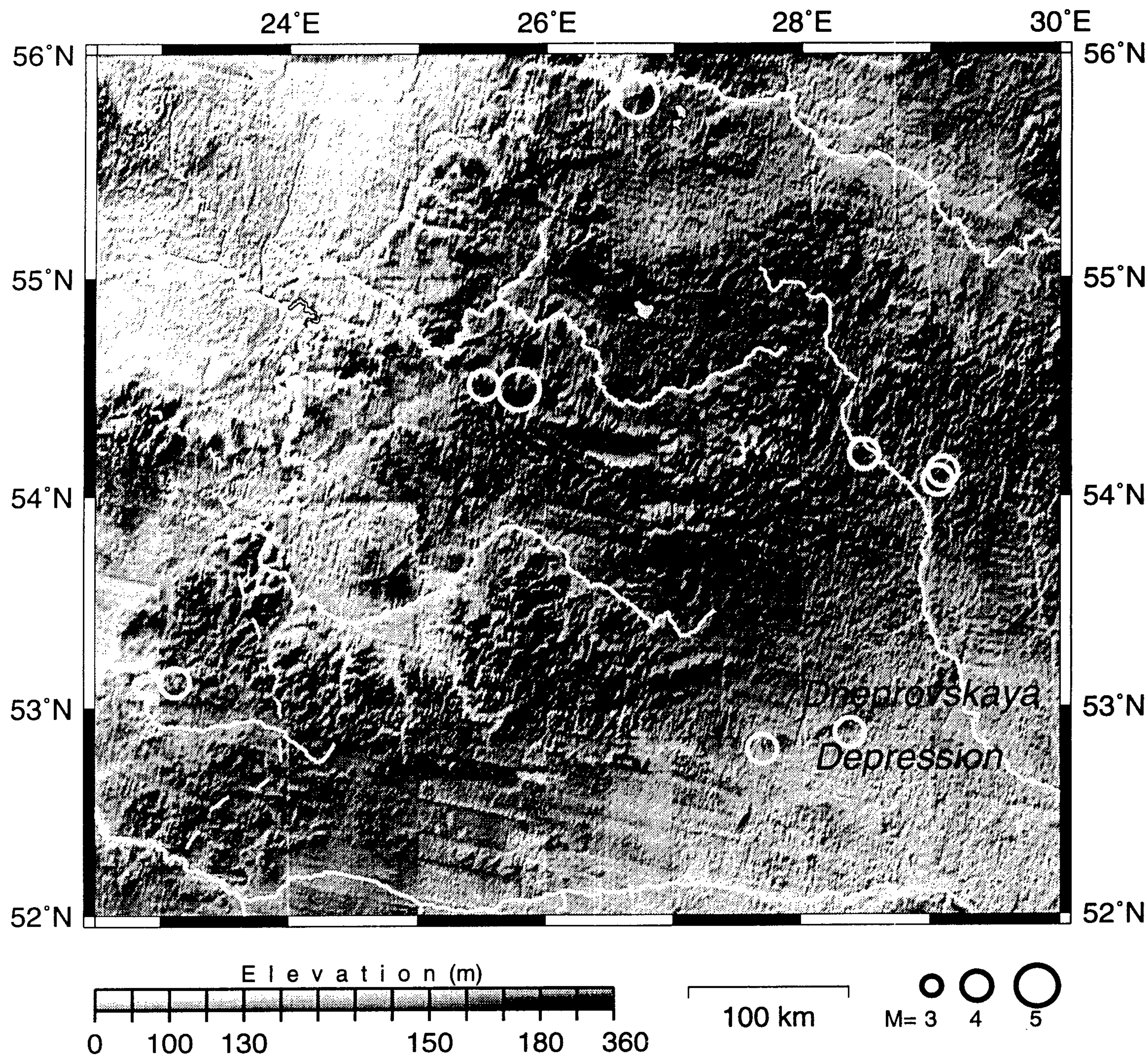
30
60
130
300
100 km
M= 3
4
5

Figure 2.1


24°E
26°E
28°E
30°E
56°N
55°N
54°N
53°N
52°N
Dneprovskaya
Depression
Elevation (m)
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100 km
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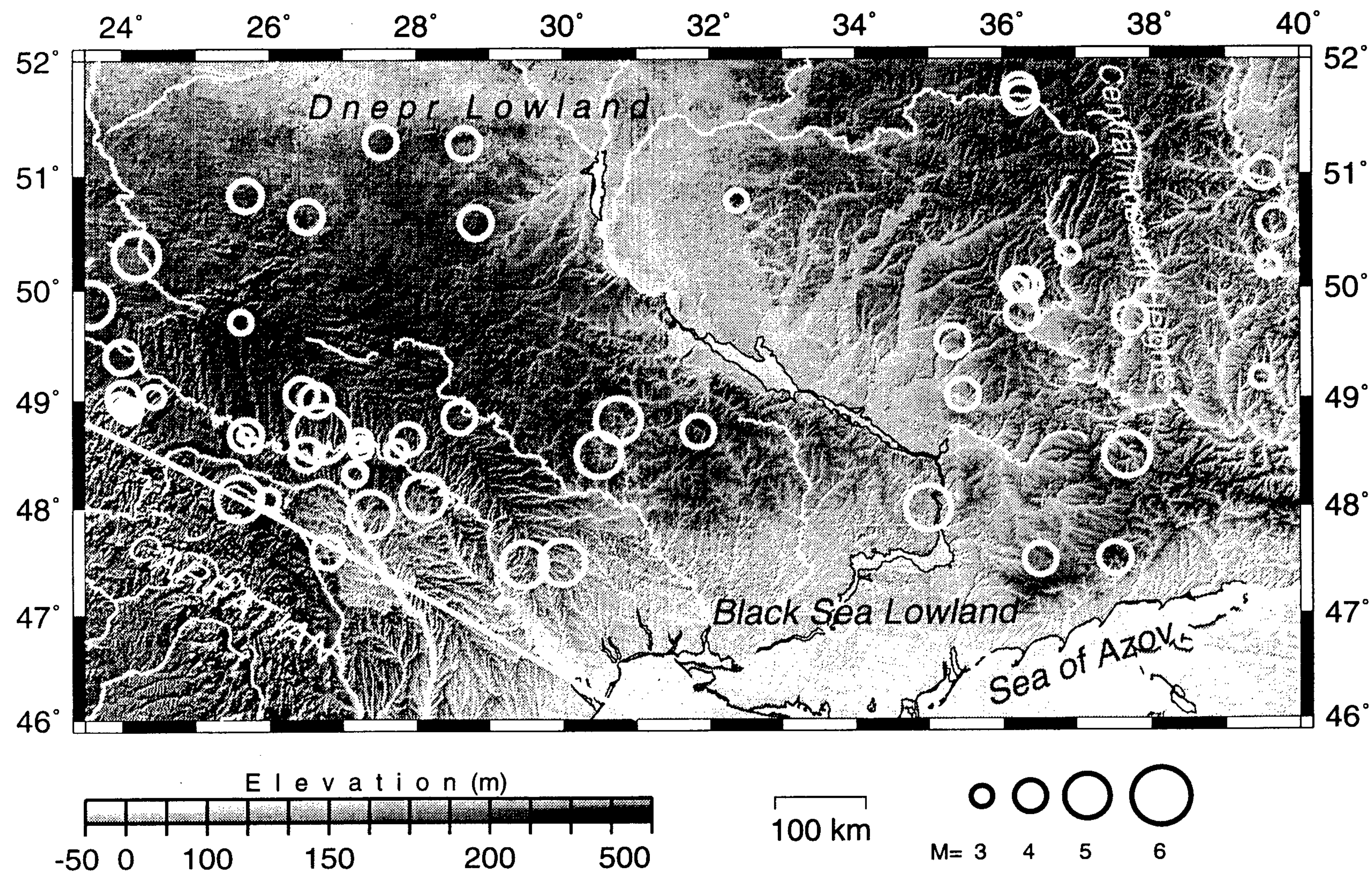
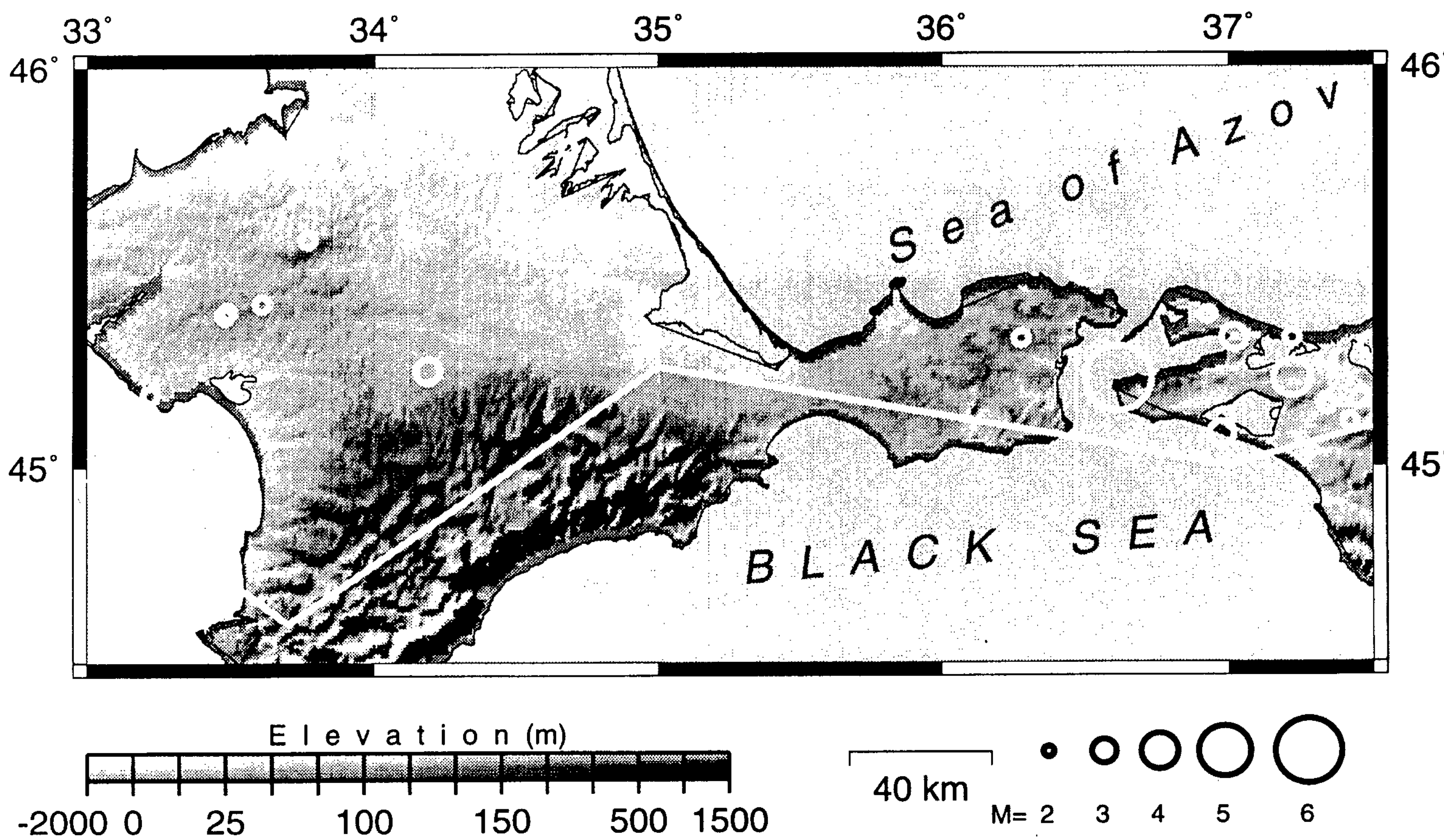
4
5



24° 26° 28° 30° 32° 34° 36° 38° 40°
52° 51° 50° 49° 48° 47° 46°
Dnepr Lowland
Central Russian Heights
Black Sea Lowland
Sea of Azov
CARPATHIAN
Elevation (m)
-50 0 100 150 200 500
100 km
M= 3 4 5 6

Figure 2.3


33°
34°
35°
36°
37°
46°
45°
Sea of AZOV
BLACK SEA
Elevation (m)
-2000 0 25 100 150 500 1500
40 km
M= 2 3 4 5 6

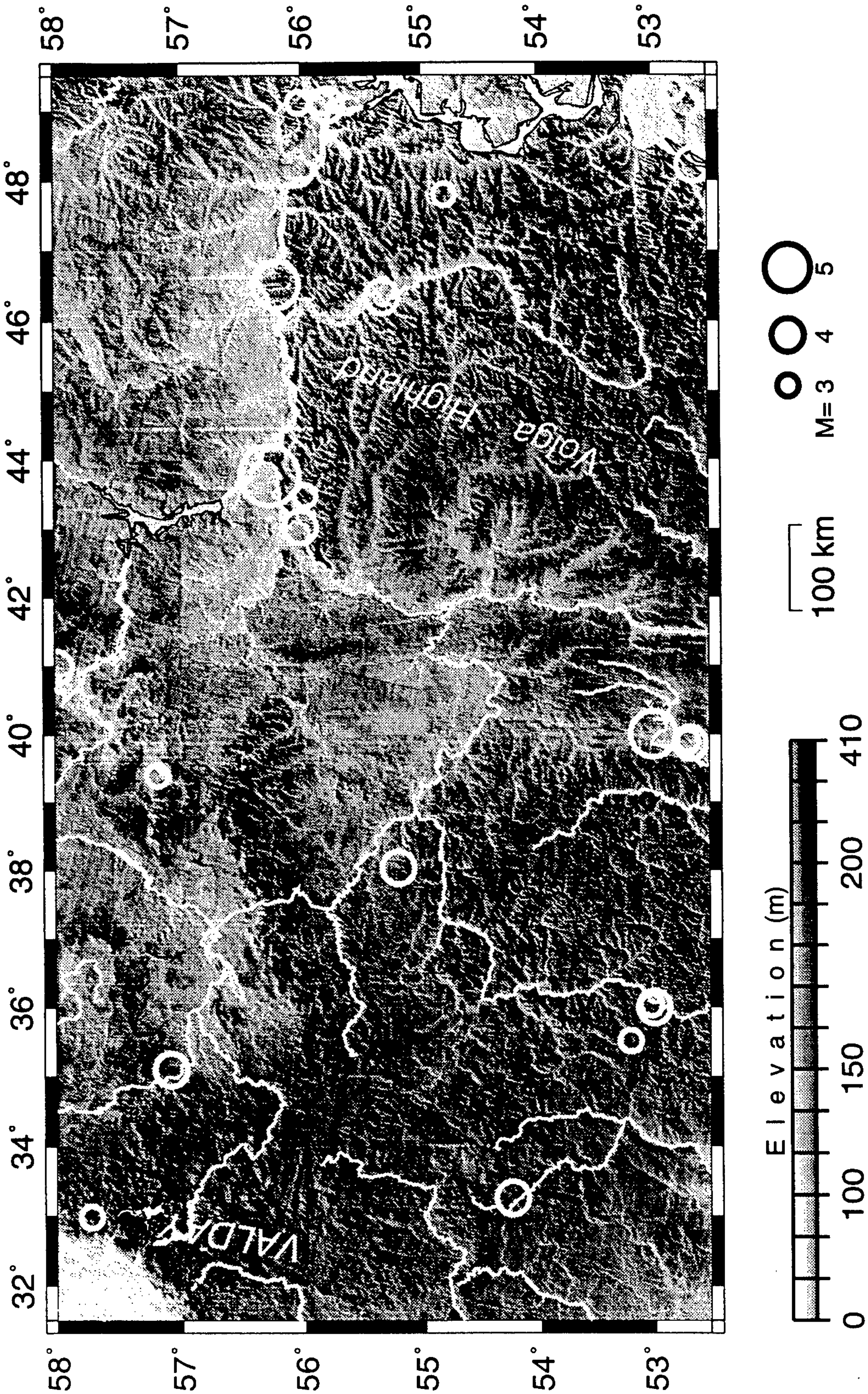

58° 57° 56° 55° 54° 53°
32° 34° 36° 38° 40° 42° 44° 46° 48°
VALDAI
Volga Highland
100 km
M= 3 4 5
Elevation (m)
0 100 150 200 410

Figure 2.5

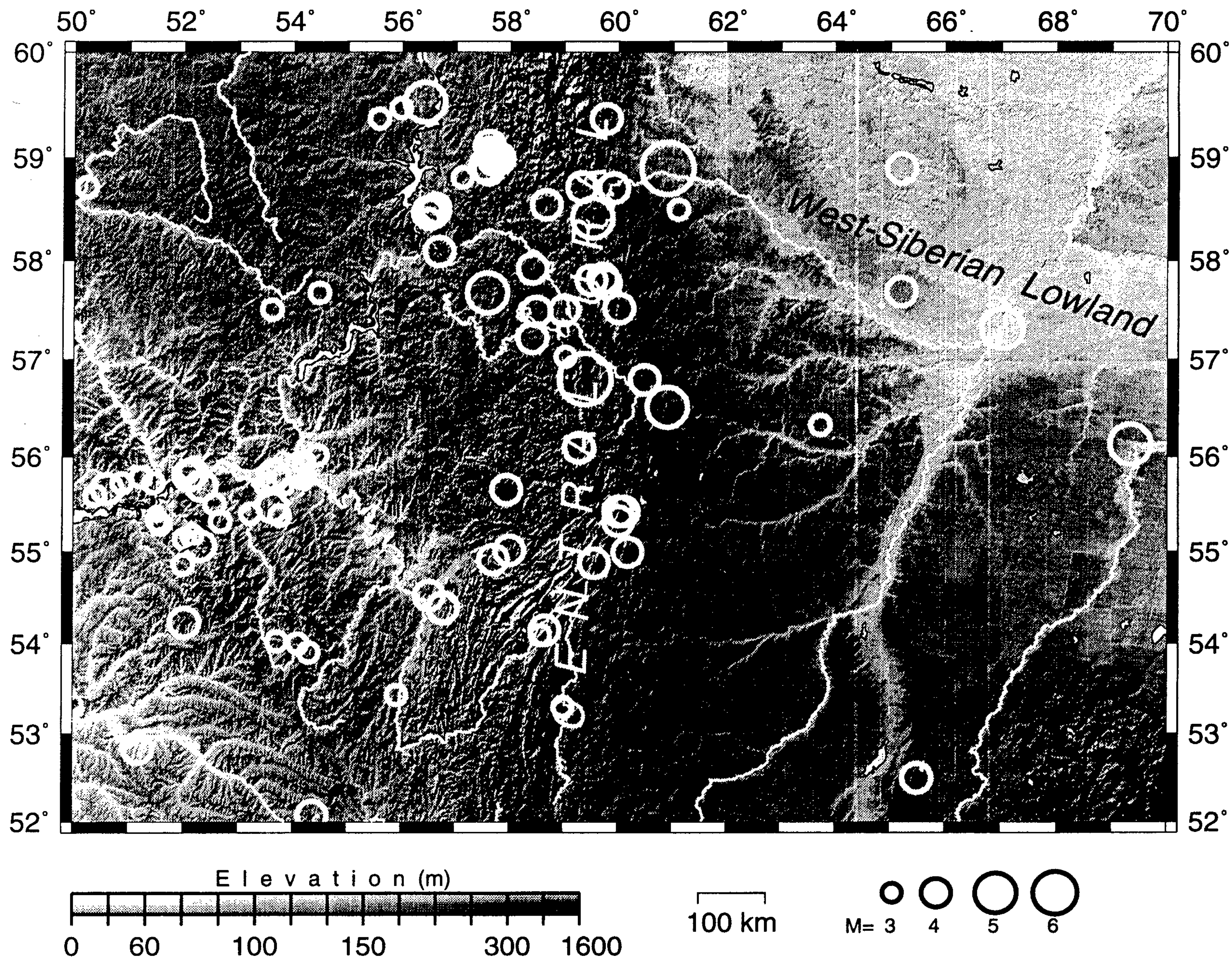
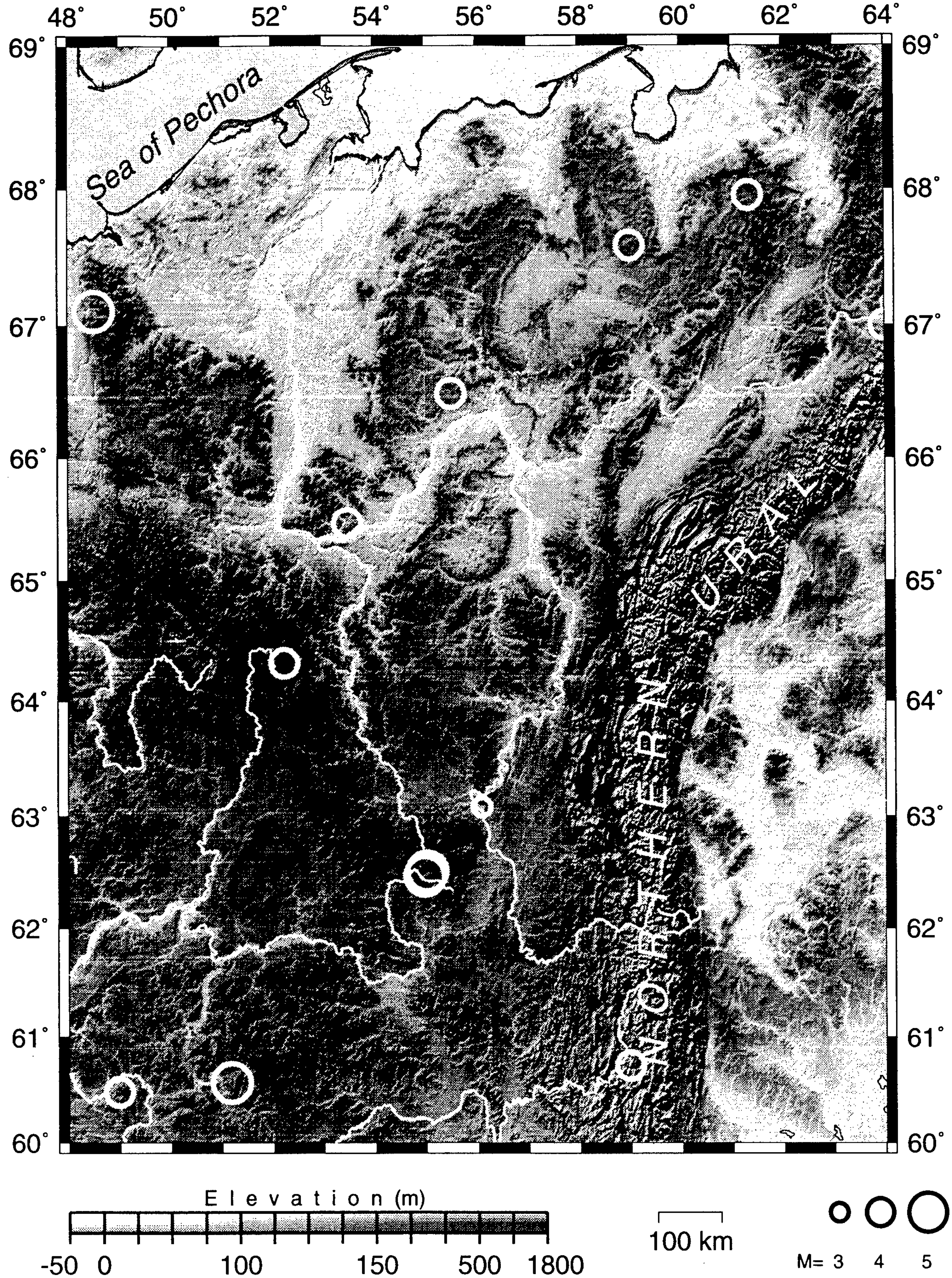
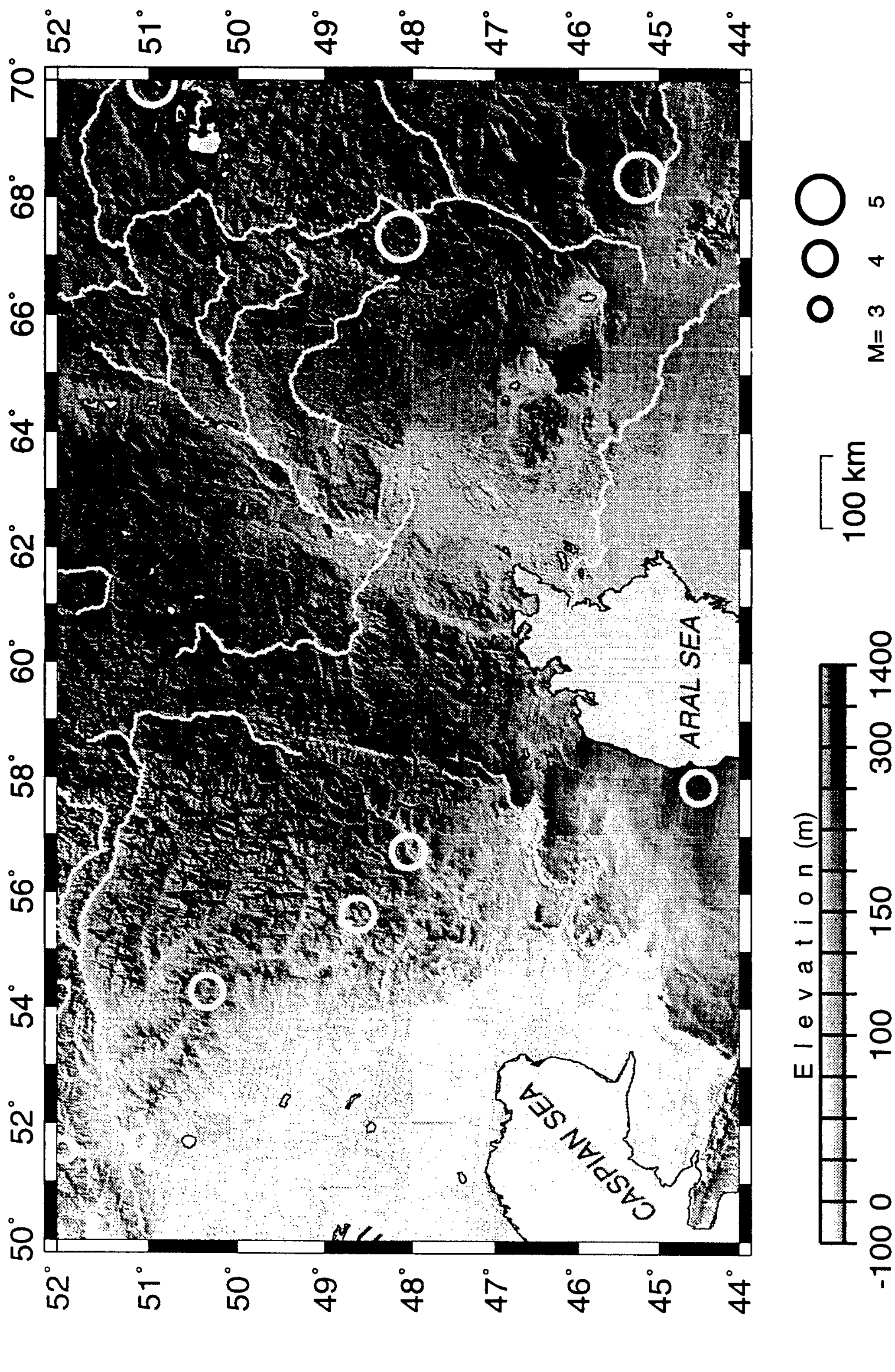

50° 52° 54° 56° 58° 60° 62° 64° 66° 68° 70°
60° 59° 58° 57° 56° 55° 54° 53° 52°
West-Siberian Lowland
Elevation (m)
0 60 100 150 300 1600
100 km
M= 3 4 5 6

Figure 2.6



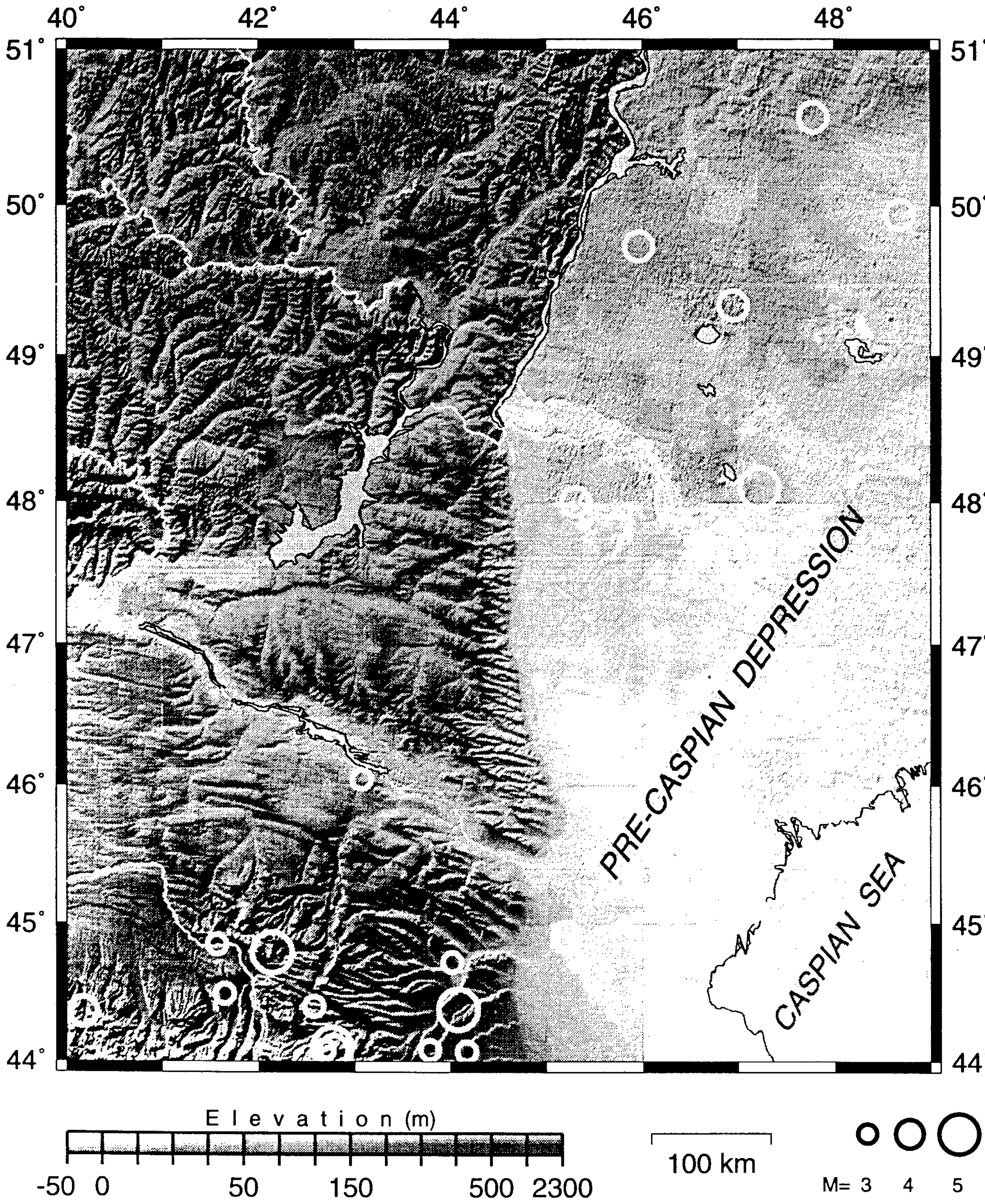
Sea of Pechora
NORTHERN URAL
48° 50° 52° 54° 56° 58° 60° 62° 64°
69° 68° 67° 66° 65° 64° 63° 62° 61° 60°
Elevation (m)
-50 0 100 150 500 1800
100 km
M= 3 4 5

Figure 2.7



52° 51° 50° 49° 48° 47° 46° 45° 44°
50° 52° 54° 56° 58° 60° 62° 64° 66° 68° 70°
CASPIAN SEA
ARAL SEA
100 km
M= 3 4 5
Elevation (m)
-100 0 100 150 300 1400

Figure 2.8



40°
42°
44°
46°
48°
51°
50°
49°
48°
47°
46°
45°
44°
PRE-CASPIAN DEPRESSION
CASPIAN SEA
Elevation (m)
-50 0 50 150 500 2300
100 km
M= 3 4 5

Figure 2.9

Low Seismicity Part to North-West of Caucasus Region

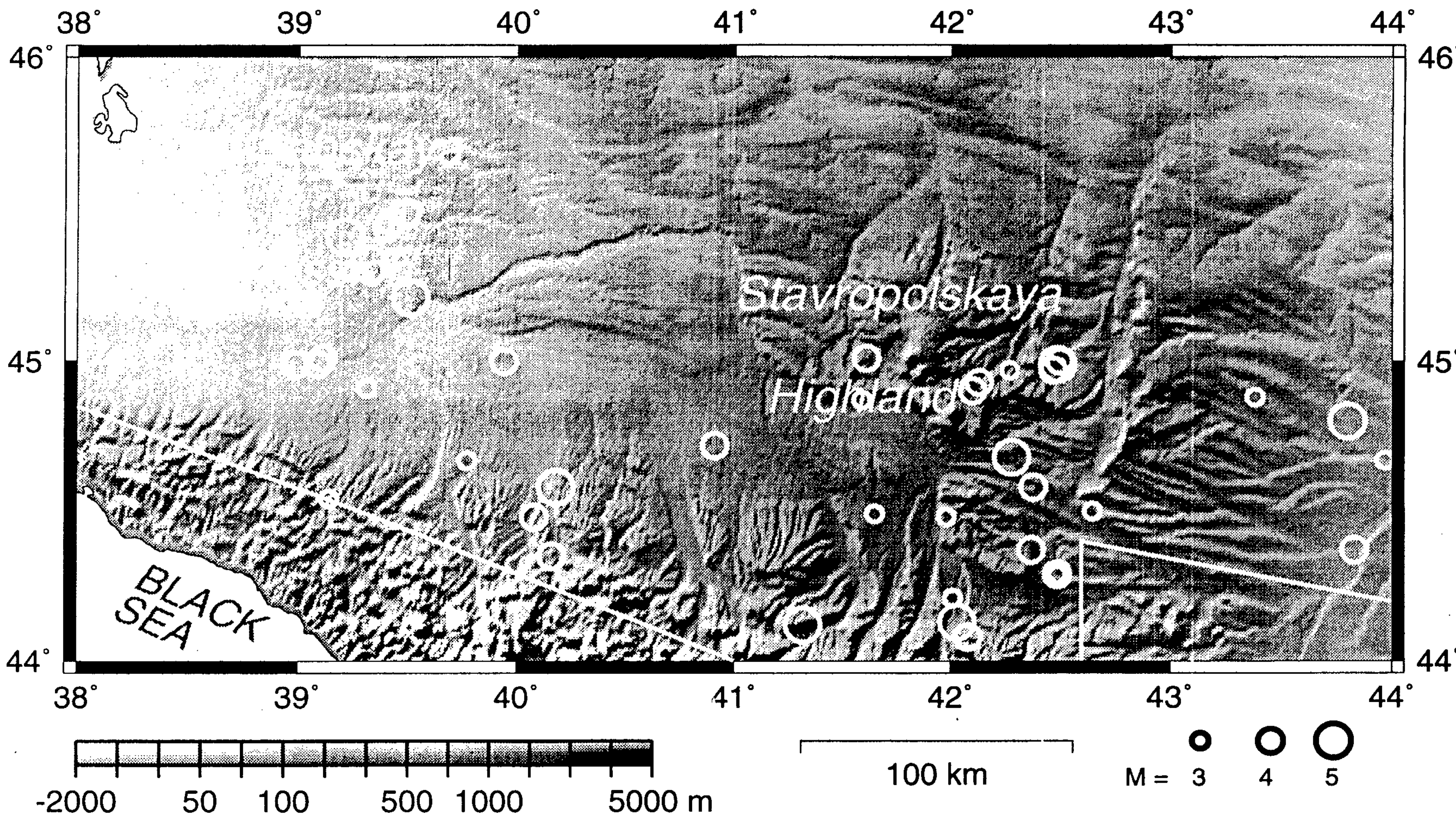
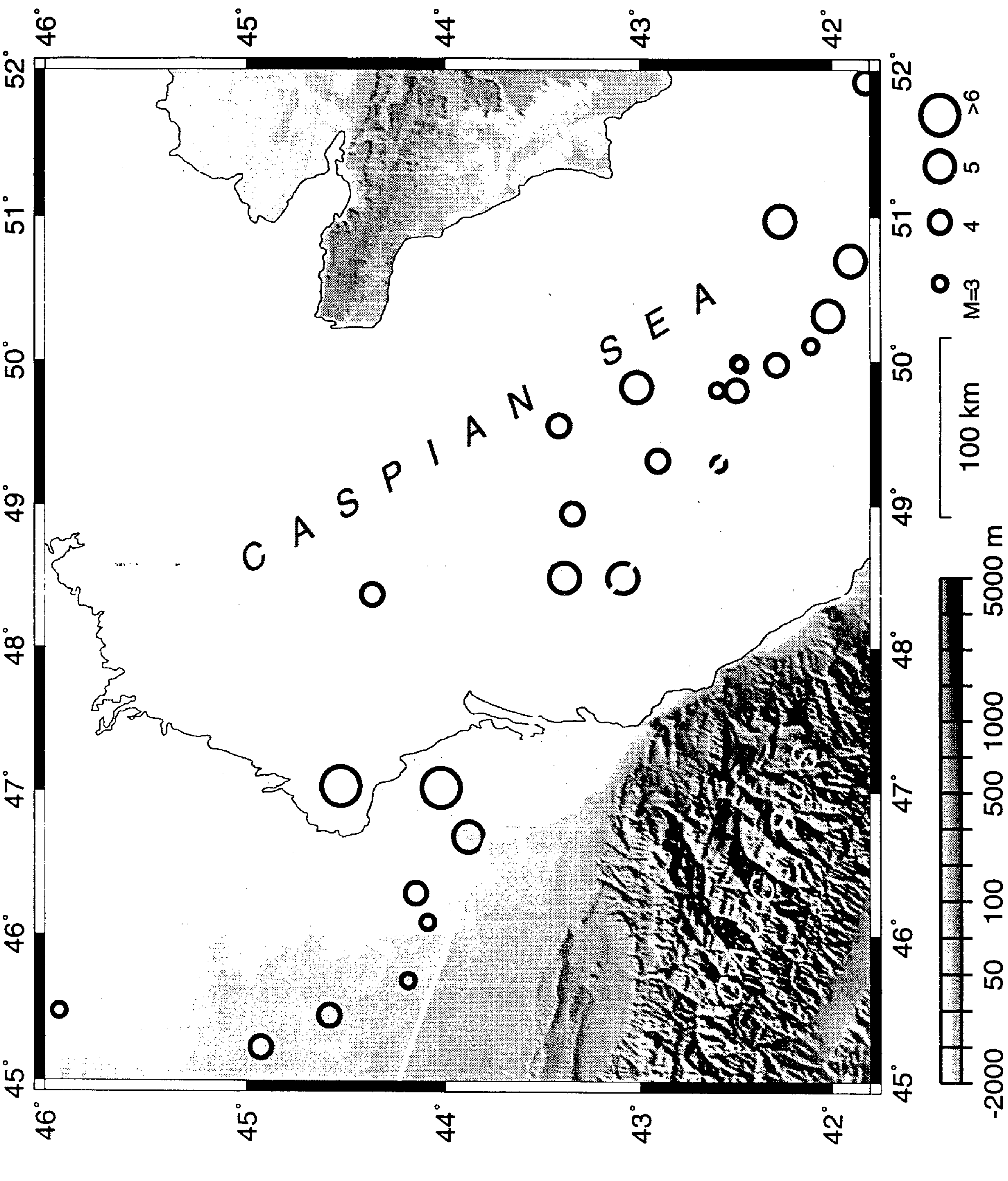


Figure 2.10



CASPIAN SEA
CAUCASUS
100 km
M=3
4
5
>6
-2000
50
100
500
1000
5000 m
45°
46°
47°
48°
49°
50°
51°
52°
42°
43°
44°
45°
46°

Figure 2.11

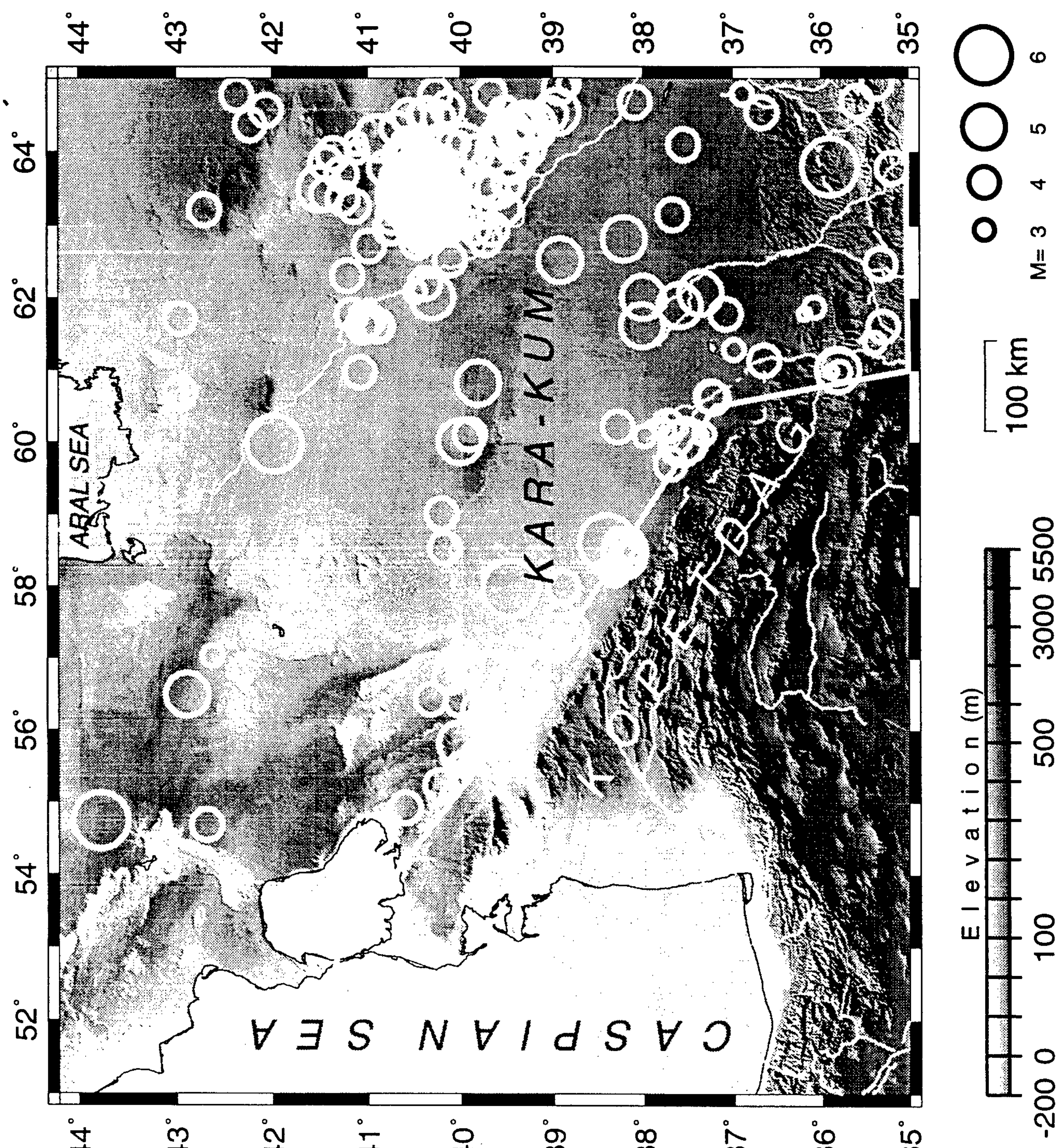

CASPIAN SEA
ARAL SEA
KARA-KUM
KOPET DAG
52° 54° 56° 58° 60° 62° 64°
35° 36° 37° 38° 39° 40° 41° 42° 43° 44°
100 km
M= 3 4 5 6
Elevation (m)
-200 0 100 500 3000 5500

Figure 2.2

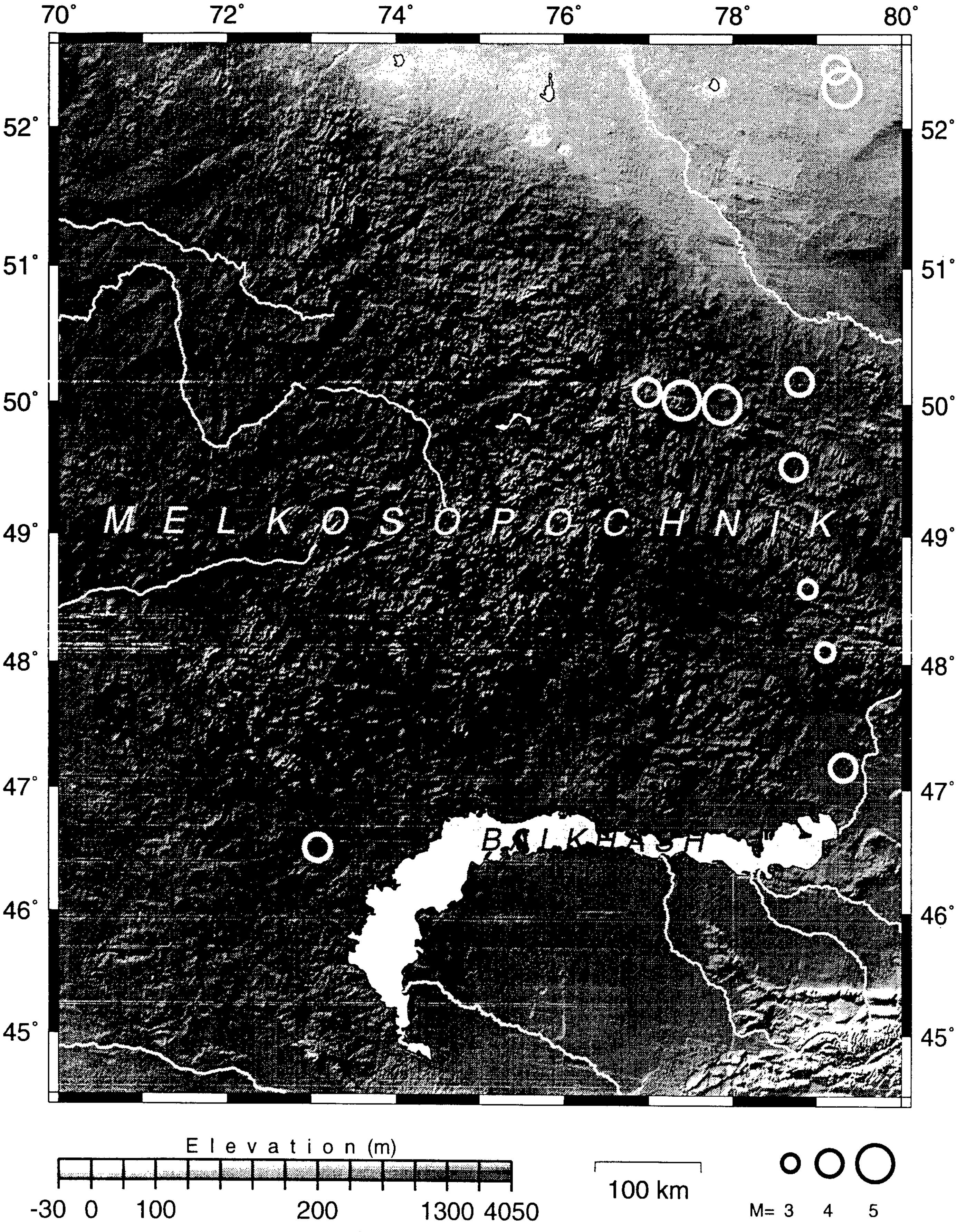

70°
72°
74°
76°
78°
80°
52°
51°
50°
49°
48°
47°
46°
45°
MELKOSOPOCHNIK
BALKHASH
Elevation (m)
-30 0 100 200 1300 4050
100 km
M= 3 4 5

Figure 2.13

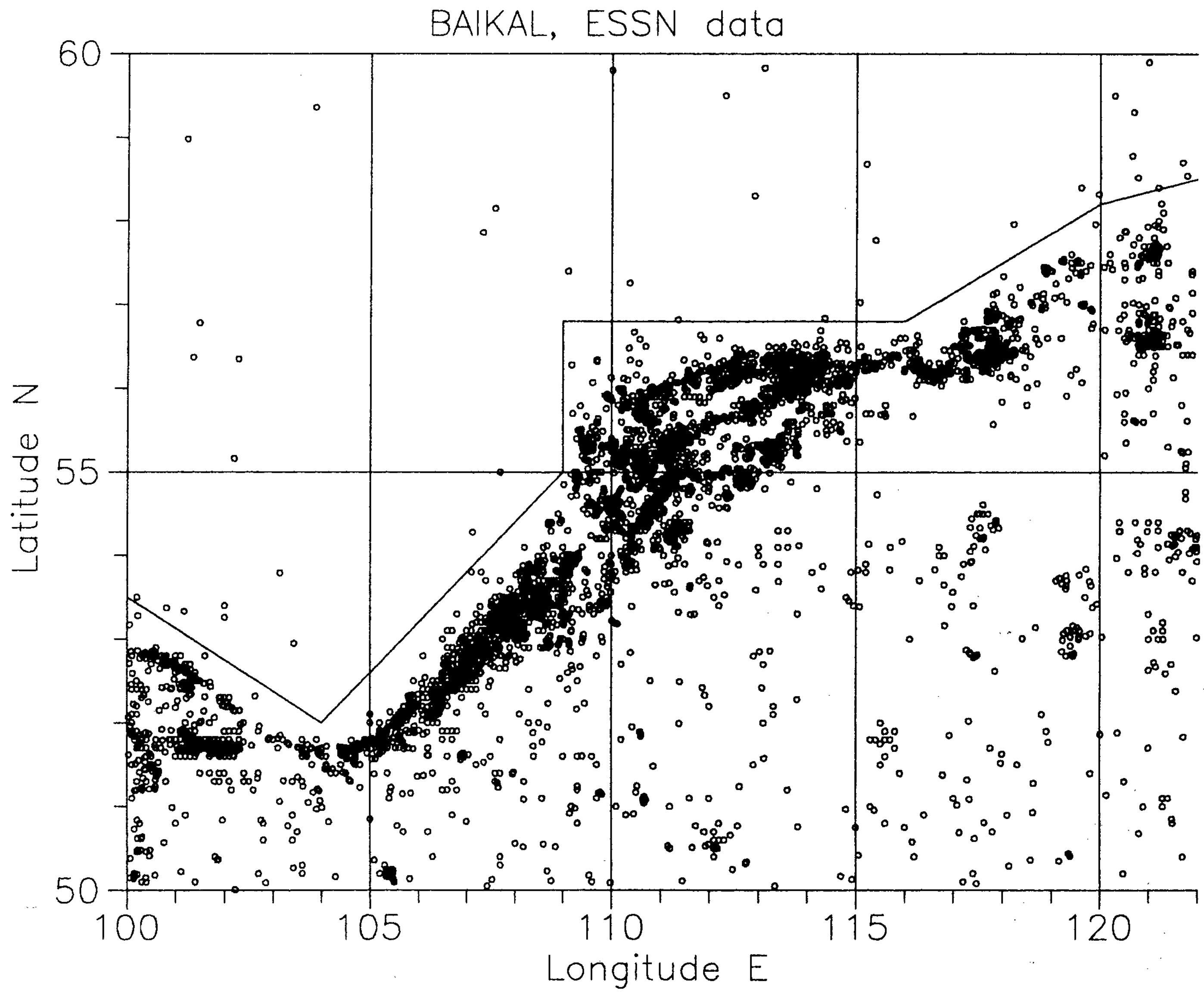


Fig. . The 8338 epicenters, 1962–1990,
with energy class K from 8 to 15

Figure 3